A Novel Application of Close-range Photogrammetry for Earth Retaining Wall and Slope Stability Assessment

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Research Article

Keywords: Retaining Wall, Unmanned Air Vehicle (UAV), Close Range Photogrammetry (CRP), Monitoring, FEM

Posted Date: May 3rd, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1534286/v1

Abstract

In recent years, with the advances in the construction sector monitoring techniques have been extended to be used in geotechnical assets such as slopes, embankments, and retaining walls. The current study analyzed the slope stability problem near the Kyrenia Castel which belongs to the 7thcentury and is located in the northern part of Cyprus. In the current case, the landslide and RC/Stone walls built for rehabilitation purposes were monitored for a period of 2 years. As a conventional analysis method, the Finite Element Method (FEM) was adapted to back analyze the current condition of the site. On the other hand, close-range photogrammetry (CRP) was adopted by using an unmanned aircraft vehicle (UAV) to obtain the required photographs that are necessary to build the dense cloud model and detect the changes in geotechnical assets. The results show that the CRP method confirms the numerical analyses. As a result, this approach can be used vastly in various civil engineering applications, especially geotechnical engineering applications, as it is proven to be fast, cost-effective, and non-destructive when compared to conventional methods.

Introduction

Regarding the importance of geotechnical assets such as slopes, retaining walls, embankments, etc. for our infrastructure systems, it is really vital to protect them from any types of failure, especially the long terms failures. These failures are mostly related to a lack of proper design or maintenance, material deterioration, and the use of unregulated backfill or poor drainage systems (Anderson& Rivers (2013), Budhu (2000), Duncan (1992), Mohammad (2005)). Monitoring of these structures is necessary because it can inform asset management during the construction service life of the structure. There are various technics for monitoring, for example, conventional methods which are precise leveling and total station surveying and it can measure the displacement. On the other hand, there are some advanced technologies such as global positioning system(GPS) measurement, interferometric synthetic aperture radar (inSAR) observation, and photogrammetry by satellite or planes. The more traditional and specific methods are local and utilized on the site for example inclinometers, strainmeters, fiber optics, etc.

The ability to acquire an extensive model of the structure when 3D reconstruction is carried out manually with a hand-held device is typically limited due to physical constraints. These problems necessitate a novel and more scalable 3D reconstruction method based on unmanned aerial vehicles (UAVs), optimal scanning methods, and powerful onboard machine learning algorithms [(Chan et al., 2021, Mauriello & Froehlich (2014), Shim (2019), Spreitzer et al., 2020). Taking advantage of UAV technology to investigate geotechnical assets can play a significant role in the creation of safe and cost-effective structures for human welfare, especially as awareness of geotechnical concerns in civil structures grows. The advantages of non-contact monitoring methods are becoming more apparent as geotechnical asset displacement monitoring systems progress toward high precision, automation, and artificial intelligence (Chae et al., 2017).

Photogrammetry actually relies on the reconstitution of objects simultaneously from different images from different perspectives. In this method, digital twin technology is used. The virtual copy of a physical object is known as a Digital Twin. The Digital Twin duplicates the exact properties and behaviors of its physical counterpart in the physical space through modeling and real-time data exchange, allowing learning, reasoning, and dynamic recalibrating for improved decision making (Glaessgen & Stargel (2012), Grieves (2014)).

This study aims to discuss the monitoring processes in order to establish a solid methodology to assess geotechnical assets via close-range photogrammetry, such as foundation excavation, slopes, retaining walls, etc. The results indicate that close-range photogrammetry is a cost-effective and non-destructive method that can be, considered a routine method for monitoring geotechnical assets. Photogrammetric approaches' accuracy and potential have also been noted in various works in recent decades (Sturzenegger & Stead (2009), Coggan et al., 2007, Martin et al., 2007, Krosley et al., 2006).

Method

There is a three-stage process for the images provided by the UAV. The stages are 3D cloud formation, georeferencing, and point cloud comparison. The formation of a 3D point cloud is a process that involves different steps. Some software packages can be utilized for these steps like PhotoScan (Agisoft) and PhotoModeler as well as open-source platforms such as Photosynth and Bundler (Harwin & Lucieer (2012), Snavely et al., 2010). For georeferencing and comparison of point clouds from various epochs, software such as CloudCompare, I-Site Studio, and 3DReshaper are perfectly useful. These software packages actually allow point cloud comparison by aligning the different epochs using existing reference points in different 3D models (Vazaios et al., 2017, Lato & Vöge (2012), Dewez et al., 2016).

Image collection

In this study, the photogrammetry process follows different steps as shown in Fig. 1. Following the flowchart, begin with, first of all, a walkover study was conducted in the location and after doing a desk study, the topography data of the study area was surveyed. After that, the location of the targets was schematized due to the initial data analyses. The retroreflective targets were printed on the A4-sized paper and later laminated to provide more resistance to climate conditions. Placing the targets on-site facilitated easy alignment from one epoch to another. On the other hand, the location of the targets was heavily dependent on the topography of the study area so the location, as well as the quantities, would be different in various areas. The targets were moreover utilized as ground control points, and the arrangement of the points has been recorded with a help of the Pentax Arrangement G6 GNSS. This array of ground control points (known points) was used in order to improve the precision of the point cloud or the digital elevation model (DEM) produced utilizing the UAVs.

In the current study, a UAV (DJI PHANTOM 3 Pro) was utilized which had been equipped with a 12-megapixel camera (Sony EXMOR). It provided 120 pictures of every epoch remotely. All the pictures collected from the UAV were supposed to overlap each other by 70%. Regarding the intact photogrammetry, the battery life and flashcard memory space were continuously checked.

Image Processing

The software utilized for image processing was PhotoScan. The advantage of using this software is that it provides an affordable solution for multi-view 3D construction. Structure-from-motion (SfM) photogrammetry gives hyper-scale three-dimensional (3D) landform models utilizing overlapping images obtained according to various points of view (Eltner & Sofia (2020), Santagati (2013)). At the site, estimations were taken to guarantee that the above standards were met and around 120 photos were taken at every epoch. Captured images were in .jpg format and their sizes were 4000 × 3000 pixels. The images were stored on a video speed class (V90) micro-SD card to enable fast recording. Pictures were straightforwardly imported from the micro-SD card to the PC with a DJI link cable. After downloading the images from the memory card, it is necessary to delete the dislocated and blurred pictures to obtain a better quality of the 3D point cloud construction. In this study, camera calibration was not necessary due to bundle adjustment (automatic estimation of camera calibration parameters using Brown's model (1966) for lens distortion) and the use of standard optical lenses and a highly redundant photo network.

After loading the taken photographs into PhotoScan, the images are aligned. This cycle, which takes 10 minutes, iteratively refines the inner just as outer camera orientations and areas utilizing the least-squares arrangement. In this stage, the software builds a sparse point cloud model and calculates the depth information based on the estimated camera positions. In the software, the command 'Build dense point cloud' can produce a single dense point. Moreover, the software operator can set the quality and depth for the point cloud generation. The computer configuration utilized in this study is an i7- 7700HQ CPU at 2.8 GHz with 16 GB of RAM and a K5000 graphics card and a 1 TB SSD hard drive.

Data Processing

For data processing, first of all, it was needed to export the generated point clouds, which were obtained from two different epochs, to the CloudCompare software in the LAZ (Lidar Data file) format. CloudCompare is open source 3D point cloud handling software. It has been initially intended to play out a correlation between two dense 3D points clouds. Before doing any comparison, the Iterative Closed Point Processing algorithm of the CloudCompare software aligns the two point clouds. It is important to consider the Close overlap between the targets to produce the best alignment of the point clouds. It has been revealed that noise and points outside the intended space ought to be taken out prior to playing out the alignment and enrollment to forestall the degradation of the enlisted point clouds.

Change identification alludes to the method involved with distinguishing the distinctions in an object by noticing it at two epochs. The regions in the point cloud where changes happened were investigated all the more intently while carrying out change detection (Sinha et al., 2010).

Case Study

Monitoring of the retaining wall of a slop beside the Kyrenia Castle

In this case study, it was tried to monitor the retaining wall of a slope located beside the Kyrenia Castle in the northern part of Cyprus as it has shown if Fig. 2 via close-range photogrammetry. As this place is located adjacent to the castle and the sea, it is really important to protect it not only because of the safety of the castle but it also important via environmental problems. The author was responsible to do an investigation via the Kyrenia municipality organization announcement about the huge erosion of the intended slope and its retaining walls.

Numerical Analyses

There are two FEM software which are geo5 and plaxis 2D were used in this study to analyze the area in 2D dimension. The results showed that the observed slide has both rotational and transitional features. The other main part that was revealed in the investigation via the FEM tools was the presence of the toe of the slide in the sea. As it is indicated in Fig. 3, the footing of the retaining walls are not passes the slide and this occurrence would load up the slide and speed up the destructive process. The movement vectors in the photo express the direction of the slide, and as can be seen there is no force there to resist the movement. From the image, it can be seen that the toe is located in the sea, and this is really important for designing the protection procedure.

Photogrammetry

In the photogrammetry process, first of all, the satellite photos of the area from 2008 to 2020 were obtained from google earth. As can be seen in Fig. 4, in 2008 there had not been any significant problem with the slope and therefore there seems to be nothing wrong with the slope; however, in 2010 the landslide started primarily and the tip was also obvious, as it was shown in Fig. 4. After three years that the destructive process of the landslide was continuing, the organization of Kyrenia Municipality decided to construct retaining walls to protect the slope in 2013, as is obvious from the related photo in Fig. 4. Due to the lack of design, the footing of the walls is embedded over the slide instead of passing through it. Therefore, these walls not only protect the slope from sliding but also aggravated it regarding their undesirable load. The destructive process has been continuing until 2020, which is indicated in the last photo can endorse while the half of car park in the picture has been destroyed in comparison with the photo in 2008.

In the photogrammetry process using an attached camera to the UAV a dense cloud image has been prepared, which can be seen in Fig. 5. The photogrammetry process has been accomplished over a period of 2 years.

This model is also known as Digital Twin, represents the virtual copy of the physical object. The Digital Twin duplicates the exact properties and behaviors of its physical counterpart in the physical space through modeling and real-time data exchange, allowing for learning, reasoning, and dynamically re-calibrating for improved decision-making (Glaessgen & Stargel (2012), Grieves (2014)).

As each pixel of the photo in Fig. 5 contains geometric data, the results of comparing these data in different epochs revealed the movement process of the wall in the specific section indicated in Fig. 5(A-A).

As it can be seen from Fig. 6, the movement of the wall from January 2018 to December 2019 occurred in different time periods. The significant displacement occurred between epoch-1 and epoch-2 and the value is about 50 cm, which is really high.

As it is indicated in the numerical study part, the toe of the slide was expected to be placed in the sea. To clarify the mentioned point as much as possible, a bathymetric survey was adopted. The bulge area was surveyed by a GNSS receiver and the topography results have been proved that the toe of the slide is in the water as it can be seen in Fig. 7. In the end for checking out the accuracy of the method, the results could be compared with the inclinometer, GNS, or laser scanner results.

Conclusions

The following conclusions are derived based on this study:

The constructed retaining walls on the slope adjacent to the Kyrenia Castle obviously increase the process of sliding and this improper design is still there and the sliding process is continuing.

The close-range photogrammetry method was adopted for monitoring the slope, provides valuable results and these outcomes endorse with high accuracy by the numerical analyses studies conducted with the geo5 and Plaxis 2D.

The comparison between the epochs in a 2 years' period (from Jan 218 to Dec 2019) revealed that the slide movement in the first year was about the total movement in two years. It can be found that after 8 years of sliding, sharp movement still can occur.

As it is obvious from the numerical analyses, the toe of the slide is placed in the sea and this phenomenon has been proved again by the bathymetric survey in the sea with the GNSS. This important fact expresses that the retaining walls are not proper protection even with an appropriate design.

It can be found from the current study that close-range photogrammetry is a safe, cost-effective, non-destructive, and accurate method for monitoring the geotechnical assets just like retaining walls and slops and also this can be considered a precise and routine method through any other issues in the geotechnical engineering.

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Figures

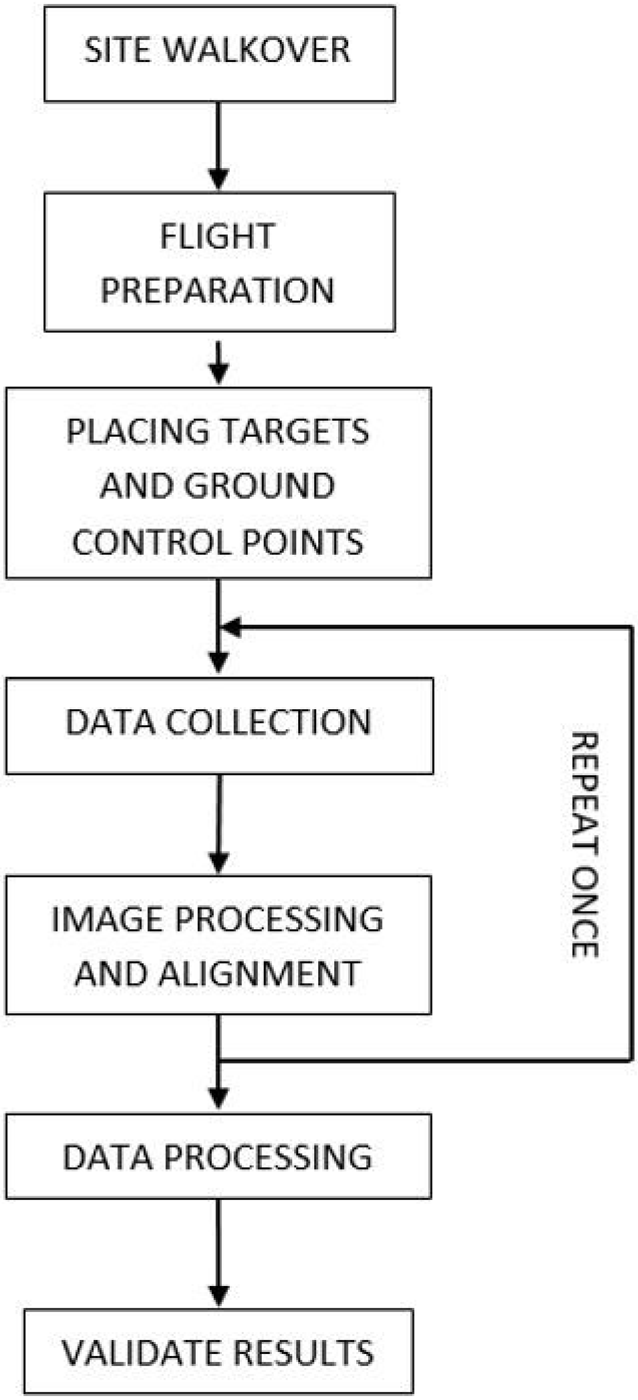

Figure 1

Flowchart representing the steps followed in aerial close-range photogrammetry study.

Figure 2

The retaining walls are located in the adjacent Kyrenia Castle in Northern Cyprus

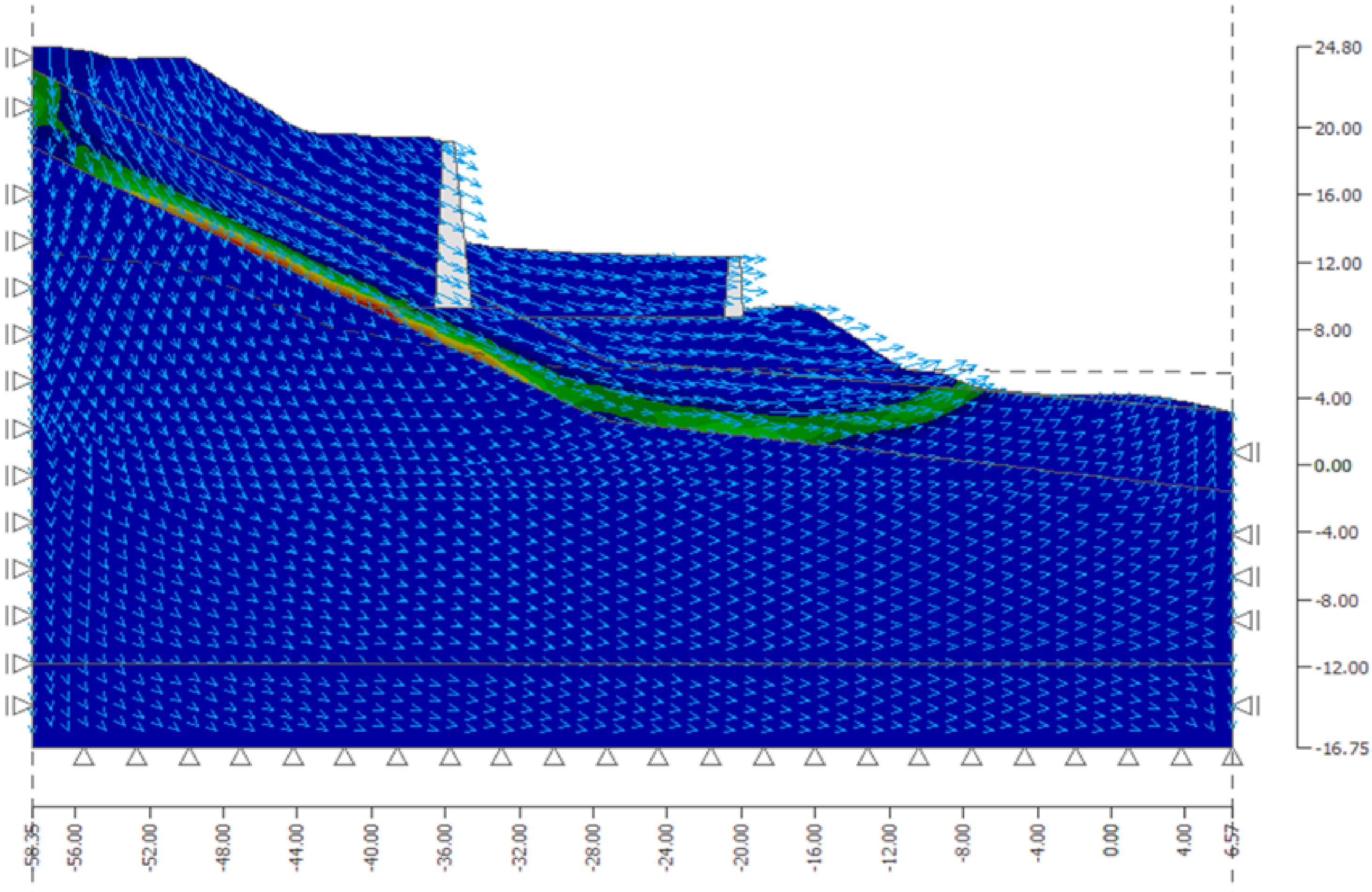

Figure 3

The schematic picture of the slide was generated with the geo5 software.

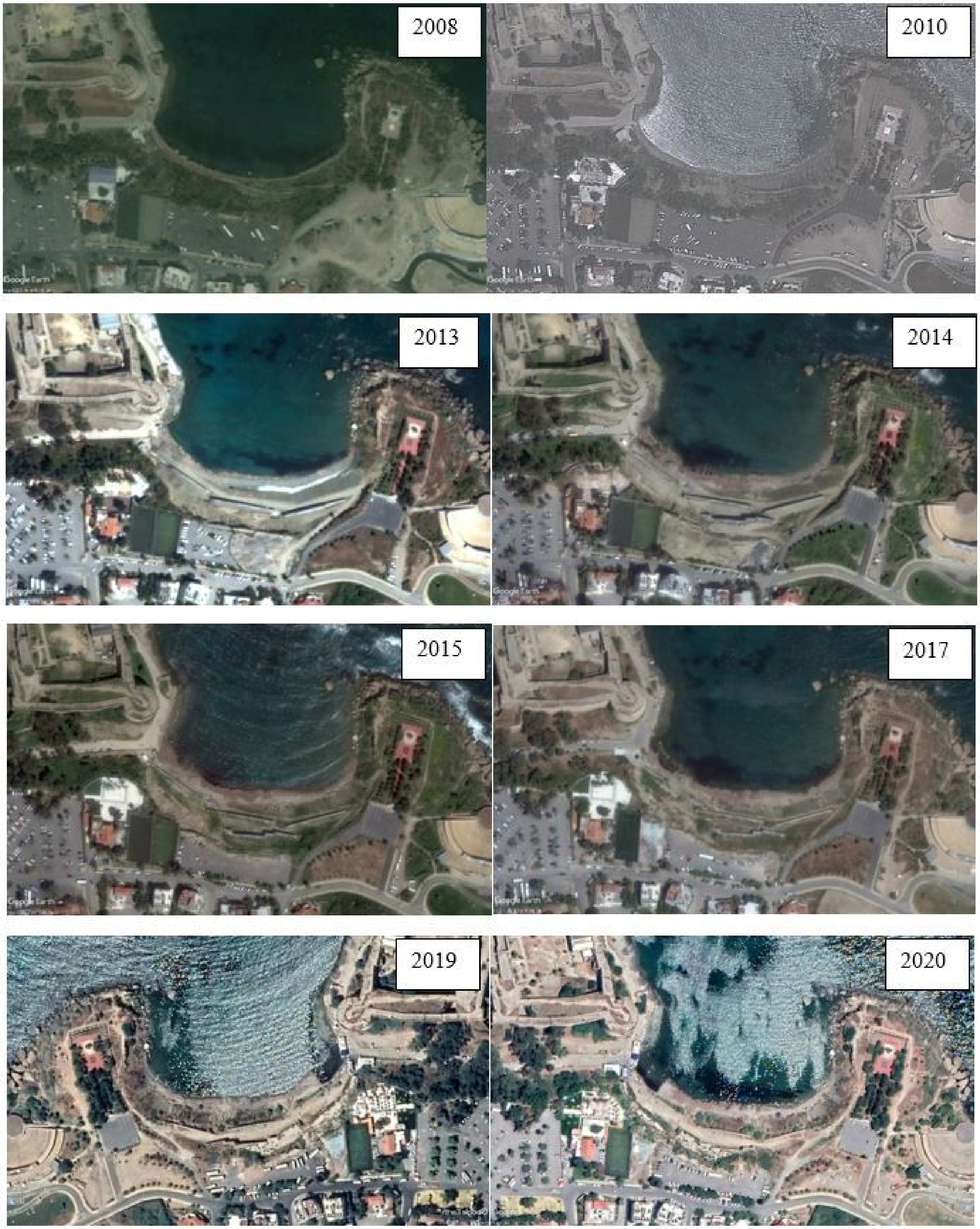

Figure 4

The satellite photos of the study area in different years

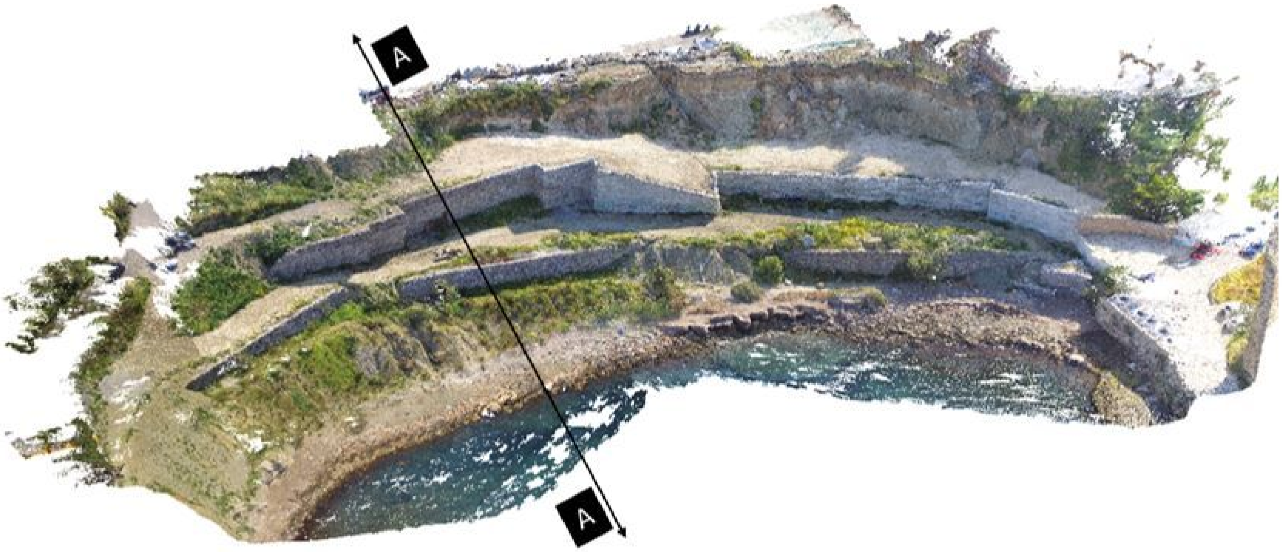

Figure 5

Point cloud of the study area with the location of the section used for comparison with the FEM analyzing

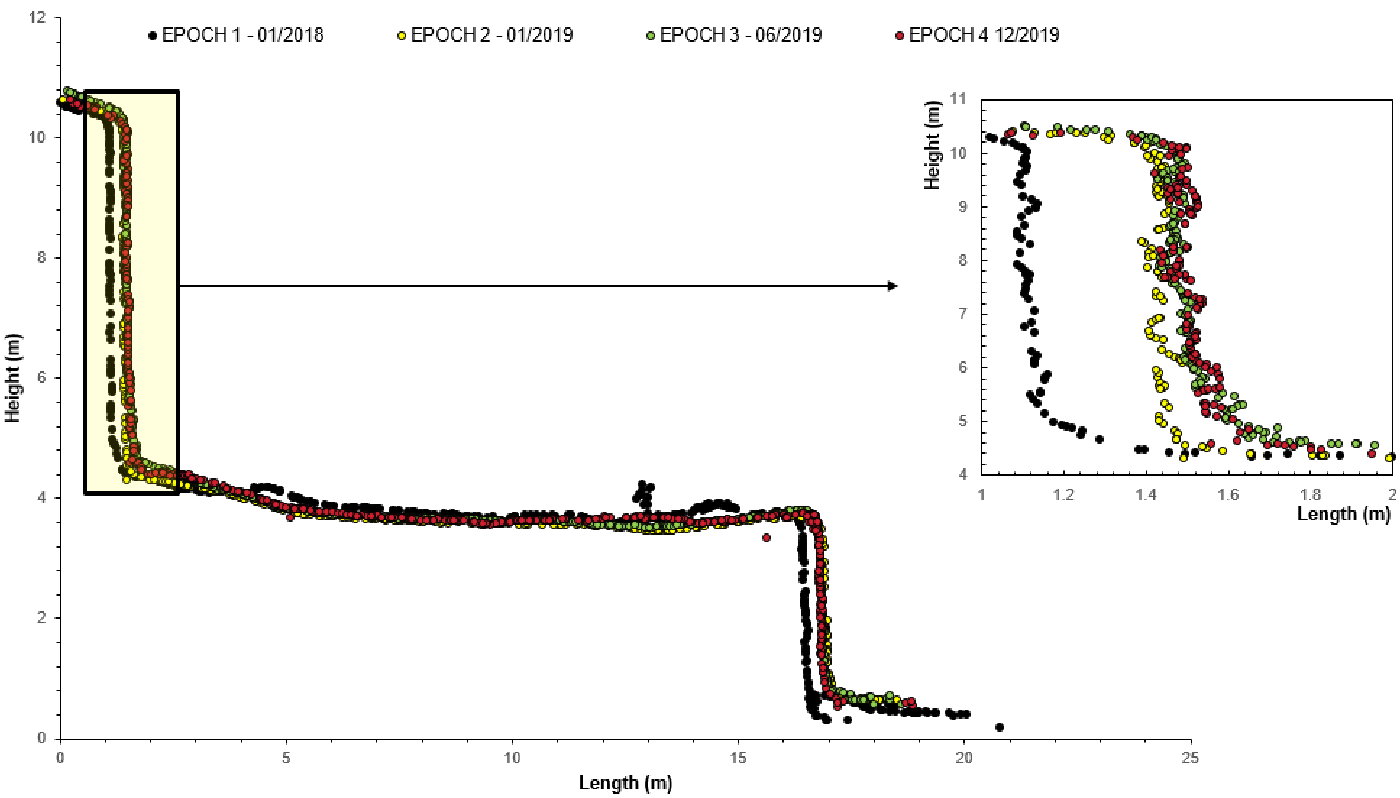

Figure 6

Comparison of epochs at section A-A with close-range photogrammetry method

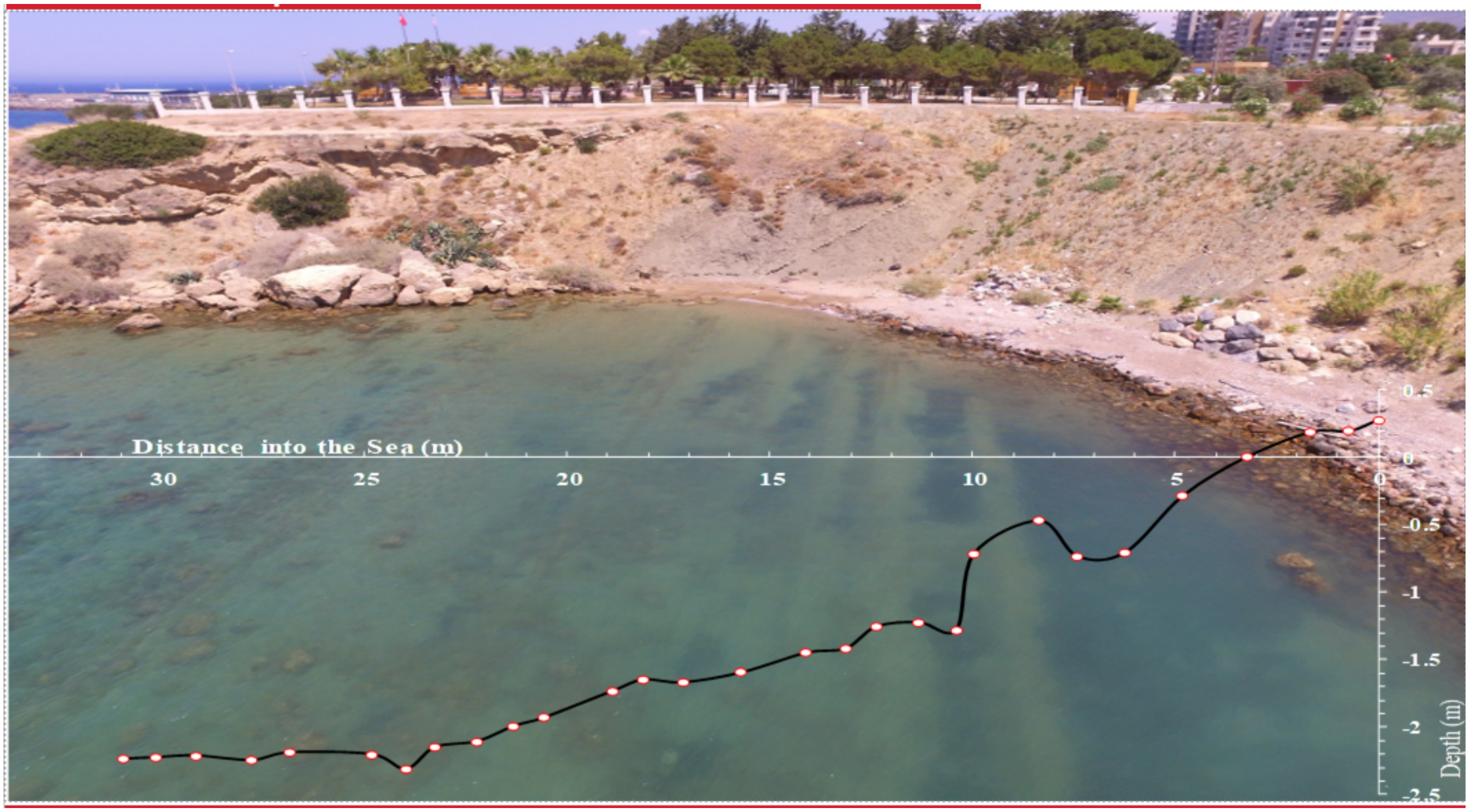

Figure 7

The bathymetric survey of the slide's toe in the sea with the GNSS